Sandwell

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CANMET, ENERGY RESEARCH LABORATORIES

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PRE-ENGINEERING ASSESSMENT OF ENERSOLVE DEMONSTRATION PROJECT

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GOVERNMENT OF CANADA
DEPT. OF SUPPLY AND SERVICES
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LIME KILN OPTIMIZATION

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LIME KILN OPTIMIZATION

SUMMARY

1. The Prince Rupert "A"-mill lime kiln operation is very energy efficient and the calculated fuel consumption compares favourably with similar size Scandinavian lime kilns, which are generally considered to be among the most energy-efficient in the world.

2. The thermal efficiency of the lime kiln can be improved further by:

   - reducing the calcining temperature and increasing the lime kiln retention time
   - reducing the radiation and convection losses from the lime kiln
   - improving the particulate collection efficiency and providing a dry dust collection system

3. The purchased fossil fuel consumption can be reduced by installing a hog fuel dryer. The use of fossil fuel can be eliminated for normal operation and fossil fuel would be required only during hog dryer maintenance.

4. The implementation program would include the following modifications and additions:

   - modifications to increase the lime kiln retention time
   - modifications to reduce the lime kiln radiation and convection losses
   - installation of a hog fuel dryer

5. The capital costs for the proposed modifications and additions outlined in 4. above have been estimated to be approximately $3,300,000. The energy and fuel savings associated with the modifications have been estimated to be approximately $1,500,000 per annum or $5.60/ADt of pulp for the "A"-mill at Prince Rupert.

6. The energy and fuel savings are attractive and the proposed modifications and additions could form the basis for a demonstration project to optimize the existing lime kiln operation and significantly reduce the consumption of fossil fuel.

7. The proposed engineering plan would consist of three phases:

   Phase I - Preliminary Engineering
   Phase II - Design Development
   Phase III - Detailed Design

   The cost of engineering services for the project has been estimated to be approximately $600,000. The engineering manhours to complete the three phases of the project has been estimated to be approximately 12,000. The Phase I work - Preliminary Engineering phase - would require approximately 650 manhours.

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LABORATOIRE DE RECHERCHE ENERGETIQUE
EVALUATION AVANT-PROJET
PROJET DE SOLUTION ENERGETIQUE

GOUVERNEMENT DU CANADA
APPROVISIONNEMENT ET SERVICES
HULL QUEBEC

DATE LE 17 AOUT 1984

OPTIMISATION D'UN FOUR A CHAUX

RESUME

1. Le four à chaux dans la fabrique "A" de Prince Rupert est très efficace en matière d'énergie et la consommation de combustible calculée se compare favorablement à celle de fours à chaux de capacité comparable en Scandinavie. On considère généralement que les fours de cette région sont les plus efficaces du monde en matière d'énergie.

2. On pourrait améliorer d'avantage l'efficacité énergetique du four à chaux par:
   - La réduction de la température de calcination et l'augmentation du temps de rétention.
   - La réduction des pertes de chaleur par rayonnement du four à chaux.
   - L'amélioration de l'efficacité de la collection des particules et la fourniture d'un système de depoussiérage à sec.

3. On pourrait réduire la consommation de combustible fossile en installant un sécheur pour déchets de bois. En exploitation normale, on pourrait éliminer l'utilisation d'un combustible fossile et celui-ci ne servirait que lors de la maintenance du sécheur.

4. Le programme d'implantation comprendrait les modifications et additions suivantes:
   - Des modifications destinées à augmenter le temps de rétention du four.
   - Des modifications destinées à réduire les pertes de chaleur par rayonnement du four à chaux.
   - L'installation d'un four à déchets de bois.

5. Le coût en capital estimatif des projets de modifications et d'additions esquissés dans 4. au-dessus serait d'environ 3 300 000 $. L'économie estimative d'énergie et de combustible associée aux modifications serait d'environ 1 500 000 $ par an, soit 5.60 $ par tonne métrique de pâte séchée à l'air d'une siccité de 90 pour cent dans la fabrique "A" de Prince Rupert.

6. Les économies d'énergie et de combustible sont intéressantes. Les projets de modifications et les additions pourraient constituer le fondement d'un projet de démonstration d'optimisation des installations du four à chaux et réduire considérablement la consommation de combustible fossile.

7. Les études techniques seraient réparties en trois phases:

   Phase I - Etudes d'avant-projet
   Phase II - Mise au point des études
   Phase III - Conception de détail

   Le coût estimatif des services d'ingénierie pour le projet serait d'environ 600 000 $. Le nombre estimatif d'heures-homme requises pour la réalisation des trois phases du projet serait d'environ 12 000. Les activités de Phase I - études d'avant-projet, nécessiteraient environ 650 heures-homme.

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LIME KILN OPTIMIZATION

INTRODUCTION

Fossil fuel used in lime kilns in kraft pulp mills in Canada totals about 350,000 m^3* of oil per annum. There is considerable interest in the pulp and paper industry in improving the energy efficiency of the lime kiln and reducing the fossil fuel consumption and also in using fuel that originates from alternative sources to displace this fossil fuel.

Sandwell has been retained by the Department of Energy, Mines and Resources of the Government of Canada, through the Department of Supply and Services Canada, to provide a detailed pre-engineering evaluation of the potential for a cost effective retrofit to improve the efficiency of one of the two lime kilns at the Westar Timber Ltd. mill at Prince Rupert, B.C.

This report presents the results of the investigations to improve the energy efficiency and optimization of the lime kiln operation and outlines a multi-phase engineering plan and a program to implement the proposed modifications.

A preliminary cost benefit analysis has been prepared for each major modification on the basis of capital cost and projected energy savings.

This report and the reports from subsequent stages of the project would serve as a useful guide to other pulp mills in Canada.

MAIN OBJECTIVES

The main objectives of the study are as follows:

1. To identify potential improvements and modifications for a cost-effective retrofit of the existing "A"-mill lime kiln at the Westar pulp mill at Prince Rupert, B.C.

2. To conduct site investigations to determine the performance of the existing lime kiln operation and to collect fuel consumption and cost data for existing fuels and potential alternative fuels.

3. To assess the savings and benefits of:

   a. Reduced fuel consumption made possible by the proposed modifications to the existing operation.
   b. Reduced fuel cost by burning alternative fuels.

4. To determine the preliminary capital costs of the proposed modifications.

5. To prepare a detailed engineering plan and an implementation program.

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* m^3 - cubic meter. For this and other abbreviations refer to Appendix I - Glossary.

SCOPE OF THE STUDY

General

Sandwell commenced the study with a review of the existing lime "A"-mill kiln operation at Prince Rupert.

The review included a site visit to collect data on the performance of the lime kiln. These data formed the basis for the material and heat balances, which were prepared for the lime kiln operation as part of this study.

The results from the material and heat balances were used in the evaluation of the energy efficiency of the lime kiln and the review of conceptual designs for equipment modifications to improve the energy efficiency of the lime kiln operation.

The anticipated capital cost of each modification was established as part of the assessment of the economic benefits of the equipment modifications.

Work Program

The work program included the following activities:

1. Calculations to determine the theoretical capacity, the production requirement and the operating parameters for the lime kiln.
2. Site visit to review the existing lime kiln operation and collect fuel consumption and cost data.
3. Review of potential options to improve the energy efficiency of the lime kiln.
4. Collection of equipment vendor information, including budget costs for major modifications and fuel preparation systems for alternative fuels for the lime kiln.
5. Preparation of material and heat balances for the existing lime kiln operation, including a review of the impact of proposed modifications on the heat balances.
6. Estimation of benefits and savings provided by the proposed modifications.
7. Preparation of preliminary capital cost estimates for the proposed modifications.
8. Preparation of a detailed engineering plan for the proposed modifications.
9. Preparation of a preliminary implementation program for the proposed modifications.

LIME REBURNING PROCESS DESCRIPTION

A simplified flow diagram for the lime kiln is included in Appendix 6.

The lime reburning process is an endothermic reaction, where lime mud ($CaCO_3$) is converted to lime (CaO) by driving off carbon dioxide (CO_2). The heat of reaction has been reported to be about 366 kJ/kg at 850°C (Angevine, 1). The most common type of furnace used for lime-reburning in the pulp and paper industry is the rotary lime kiln,

which typically consists of three parts; the drying, the preheat and the calcining zones. The lime mud is stored in slurry form and dewatered on a rotary drum filter. The lime mud is fed from the dewatering filter to the dry zone of the lime kiln at about 70% dryness and is heated to about 850°C. The lime mud is heated close to the calcining temperature in the preheating zone. For optimum calcining, the temperature in the calcining zone should be maintained in the range 1000°C to 1150°C (2). The conversion of calcium carbonate to calcium oxide takes place in the calcining zone. The heat of the reaction is provided by the fuel, typically heavy fuel oil or natural gas, while maintaining the temperature of the solids in excess of 850°C.

The fuel is introduced into the calcining zone through an air- or water-cooled burner system. The waste heat flow from the calcining zone is determined by the quantity, temperature and CO_2-concentration at the outlet of the calcining zone. The quantity of water that can be evaporated from the lime mud is determined by the waste heat flow. It has been calculated that the flue gases contain enough waste heat to remove water from lime mud having a moisture content of between 68% and 70% (1).

The flue gases contain a significant amount of particulate, mainly lime dust, which must be removed in order to minimize particulate emission and dust fallout from the lime kiln stack. The most common device used to reduce the particulate emission is a wet-venturi scrubber. Both high- and low-pressure-drop scrubbers are used in this service. Recently several mills have installed high-efficiency electrostatic precipitators to minimize the particulate emissions.

SITE INVESTIGATIONS

A detailed review of the existing operation was carried out on 1 and 2 May, 1984.

Data were collected on the present lime kiln operation, which formed the basis for the lime kiln material and heat balances.

Equipment specifications and design data were obtained from the mill files and this information was used in the evaluation of the capabilities of the existing equipment. The lime kiln design data have been summarized in Appendix 2.

Data on actual fuel consumption and fuel costs, including alternative fuels such as wood waste, were provided by the mill. These data have been summarized in Tables 1, 2 and 3 in Appendix 3 of this report.

The production statistics for 1983 were reviewed and the month of November was selected as the base month for the lime kiln performance evaluation. The process load and production capacity requirements were established and compared with the original design parameters for the lime kiln. The operating statistics have been summarized in Table 5 in Appendix 3 of this report.

LIME KILN PERFORMANCE REVIEW

General

The lime kiln at Prince Rupert is a 3.7 m dia. x 99 m long rotary kiln, designed and manufactured by the Traylor Division of the Fuller Company. The kiln is equipped with

Warner integral planetary coolers. A venturi scrubber is used to control the particulate emissions from the lime kiln. The scrubber is a Chemico-SF wet scrubber. The fuel used in the lime kiln is natural gas, which is introduced through a Peabody natural gas burner, convertible to fuel oil firing through mechanical atomization of No.6 fuel oil.

The performance review is based on the information collected during the site visit on 1 and 2 May 1984. In addition, operating data for the month of November 1983 were used to establish the performance of the lime kiln over a one-month period.

Capacity Requirements

The design capacity of the Prince Rupert "A"-mill lime kiln is 215 t CaO/d, which can support a bleached pulp production of approximately 730 ADt/d. The present lime kiln production requirement ranges between 205 and 260 t CaO/d. It would appear that the lime kiln can be operated satisfactorily at lime production rates up to 20% above the original design capacity and therefore the kiln has adequate capacity to support the present bleached pulp operating rate of the Prince Rupert "A" pulp production line; the lime kiln is presently not considered to be a production bottleneck.

Product Quality Requirements

The size of the reburnt lime pellets is an indication of the quality of the lime. The ideal size of the pellets has been reported to be between 1 and 6 mm (3). An excessive fines fraction of the lime produces a lime mud with poor settling properties and results in increased losses at the slaker and dregs washer. An excessive fraction of larger pellets contains a larger portion of unburnt lime and should be kept at a minimum to reduce the amount of carbonate carry-over.

Other factors affecting the quality of the lime are the calcining temperature and calcining-zone retention time. The porosity of the lime is determined mainly by the rate of heating prior to and during calcination. The porosity, surface area and reactivity of the lime are closely related. It has been determined that the specific surface area decreases with increased temperature. The surface area also decreases with reduced retention time at a constant temperature. It has also been established that there appears to be a critical calcining temperature, above which the reactivity decreases rapidly. The reactivity is a measure of the lime slaking properties.

The lime quality can be maintained at a high and uniform standard by:

- optimizing the calcining-zone retention time
- minimizing rapid load changes in the kiln
- maintaining a constant and optimum excess-air flow, which will also improve the thermal efficiency

Operating Parameters

The operating parameters for the Prince Rupert lime kiln were provided by the mill and were reviewed with the lime kiln operating personnel during the site visit. The operating parameters and production statistics recorded during the site visit on 1 and 2 of May, 1984 have been summarized in Table 4 in Appendix 3 of this report. The production statistics and operating parameters for the month of November 1983 were selected by the mill as a typical month of lime kiln and pulp mill operation. The data were collated, reviewed and the average for the month calculated. These data provided the basis for all evaluations

and calculations, presented in this report. The statistics have been summarized in Table 5 in Appendix 3.

Fuel Consumption

The Prince Rupert kiln is designed to operate on natural gas with a back-up system for fuel oil. The average natural gas consumption for the month of November 1983 has been calculated to be 31,300 m^3/d. The natural gas consumption is calculated from the daily average reading on the natural gas flow recorder at the lime kiln control panel. The November 1983 average consumption represents a specific heat input from natural gas of approximately 5.3 GJ/t CaO. In addition, approximately 1.6 GJ/t CaO is provided by the firing of non-condensible gases in the lime kiln. The total specific heat input is therefore approximately 6.9 GJ/t CaO . However, the heat balance for the present lime kiln operation would suggest a calculated total gross heat output of approximately 8.4 GJ/t CaO. It would therefore appear that there is a discrepancy in the method of measuring the heat input, probably caused by an error in the conversion factor used to calculate the natural gas flow from the lime kiln flow recorder. The actual cause can probably be determined only by dismantling the existing instrument to check the orifice size and then to determine the pressure drop across the orifice.

The non-condensible gases are waste gases from the pulping process, and consist of off-gases from the digester hot water condenser and foul condensate stripper and vented gases from black liquor and foul condensate storage tanks. The major components of the non-condensible gas include mercaptans, organic sulphides and inorganic sulphur compounds.

The energy balance for the present operation has been summarized in Appendix 4.

The performance of the Prince Rupert lime kiln has been compared with similar-sized lime kilns operated by Scandinavian pulp mills (4). Typical fuel oil consumptions for some Canadian lime kilns are also shown (5). The comparison is presented in Table 1.

Table 1 - Comparison of Lime Kiln Fuel Consumptions

Lime Kiln-Size Dia x L (m)	Type of Fuel	Fuel Consumption kg/t CaO	Heat Input GJ/t CaO
Scandinavian Lime Kilns			
3.3 x 86	Fuel Oil	170	9.7
3.8 x 94	Fuel Oil	180	10.2
3.2 x 104	Fuel Oil	185	10.5
3.6 x 104	Fuel Oil	190	10.8
3.8 x 113	Fuel Oil	168	9.6
3.6 x 116	Fuel Oil	155	8.8
Canadian Lime Kilns			
Varies	Fuel Oil	180-220	10.2 -12.5
Prince Rupert Lime Kiln			
3.7 x 99	Natural Gas	220 (m^3/t CaO)	8.4

The fuel consumptions in Table 1 have been adjusted for auxiliary fuels, such as propane, non-condensible gas and methanol where applicable in order to arrive at a true comparative fuel consumption. As shown in Table 1, the Prince Rupert lime kiln fuel consumption is comparable to the fuel consumption reported for Scandinavian lime kilns, all of which are equipped with coolers. Therefore, the achievable energy savings are comparatively small. The potential energy savings are greater for the typical Canadian lime kilns, most of which are not equipped with coolers.

OPTIONS TO IMPROVE ENERGY EFFICIENCY

Increased Lime Kiln Retention Time

The lime retention time in the kiln is an important variable which must be considered during the optimization of the lime kiln operation. Mill trials (3) have demonstrated the impact of the lime retention time on the quality of the reburnt lime. An increase in retention time from 1 hour to 2½ hours, combined with a reduction in calcining temperature from 1200°C to 1000°C resulted in a more uniform lime quality, a reduction in fuel consumption of 14% and a reduction in make-up lime from 5% to 3.3%. The increase in retention time was achieved by reducing the speed of the lime kiln from 1 1/3 rpm to 1.0 rpm and increasing the dam height in the lime kiln from 370 mm to 670 mm.

The Prince Rupert lime kiln is presently being operated with a calcining temperature of approximately 1060°C, which is close to the optimum temperature. A reduction in the calcining zone temperature to 1000°C would be possible and would reduce the heat consumption by approximately 1% or 50 MJ/t CaO which represents a potential saving in fuel cost of $14,000 per annum based on the current price of $0.135/m^3 of natural gas.

The energy balance for this modification has been summarized in Appendix 4.

The reduction in calcining-zone temperature should be combined with a reduction in kiln speed from the present average speed of 1.2 rpm to 1.1 rpm and an increase in the kiln discharge-end dam height to approximately 500 mm, which would increase the retention time and compensate for the lower calcining-zone temperature. The increased lime retention time should not reduce the capacity of the lime kiln. It is recommended, however, that tests be conducted to confirm the capability of the existing drive to handle the additional dynamic weight of the lime kiln.

The capital cost for the modification to increase the kiln dam height has been estimated to be approximately $3,000.

Based on the capital cost of $3,000 and a potential saving of $14,000 per annum, the simple payback would be approximately 0.2 years.

This modification is very economical and should be considered in the program to reduce the Prince Rupert lime kiln energy consumption.

Modifications to Reduce Radiation and Convection Losses

A considerable amount of heat is lost through radiation and convection from the lime kiln calcining zone. Several pulp mills (6) have reduced these losses by painting the lime kiln with low-emissivity high-temperature aluminum paint. Fuel savings in the order of 5 to 6

percent have been reported by these mills. The high-temperature paint must be combined with an enclosure and cover over the lime kiln to protect against wear and heat losses caused by rain and wind penetration.

The Prince Rupert lime kiln was originally designed to operate with a refractory lining of 230 mm. Presently, however, a 150 mm refractory lining is used in the lime kiln and this refractory should be replaced with the more energy-efficient 230 mm refractory lining as part of the lime kiln optimization program.

The capital costs to paint the hot end, install an enclosure and install a 230 mm refractory lining in the Prince Rupert lime kiln have been estimated to be $260,000.

The energy balance for this modification has been summarized in Appendix 4.

The potential savings have been calculated based on the estimated present fuel consumption and the results are summarized in Table 2.

Table 2 - Savings Provided by Reduced Radiation and Convection Losses

Item	Unit	Amount
Present fuel consumption	GJ/t CaO	6.7
Projected saving	GJ/t CaO	0.7
Equivalent fuel	m^3/t CaO	18.2
Fuel saving	$/ADt	0.75
	$/a	200,000

Based on the estimated capital cost of $260,000, the simple payback would be approximately 1.3 years, which would indicate that this option should be considered in the Prince Rupert lime kiln optimization program. If this option were combined with lime calcination at the recommended lower temperature, then the fuel saving would be reduced to approximately $185,000 and the simple payback for this option would increase to approximately 1.4 years.

Product Coolers

The Prince Rupert lime kiln is equipped with eight integral planetary coolers designed by Warner. This type of cooler has been used in other industries for a number of years, but is not commonly used on lime kilns in the pulp and paper industry in North America.

However, Warner or similar planetary coolers are standard equipment on Scandinavian-designed lime kilns. The planetary coolers on the Prince Rupert lime kiln have been designed to remove approximately 475,000 kJ/t CaO produced. The heat removed from the product is returned to the lime kiln as preheated secondary air.

It is important that the coolers be designed so that the temperature of the lime leaving the coolers will not be so low as to cause difficulties in the lime slaking process.

The planetary coolers on the Prince Rupert lime kiln are performing well and no further modifications should be considered in the program to reduce the lime kiln energy consumption.

Chain Section Modifications

The purpose of the chain section is to provide maximum surface area for the drying of lime mud. Flue gas waste heat is used to evaporate water from the mud slurry travelling in the opposite direction to the flue gas flow inside the rotary kiln. The chains are usually welded to the lime kiln shell and located such that they form a spiral passageway, which conveys the lime mud through the drying section. It is important that the chain section be sized to suit the solids content of the lime mud feed. The lime mud should not be completely dried until after it has passed through the chain section. Mill experience has shown that if the lime mud were to dry in the chain section of the kiln, a large amount of small size particles would be produced and the amount of solids carry-over in the lime kiln off-gas increased.

Several pulp mills have installed high-density-chain sections in the lime kiln (7). This type of chain system was developed for wet rotary kilns used in the cement industry. The chains are suspended by one end only, allowing for free movement in the flue gas stream. Three starting points are employed, located 120 degrees apart around the circumference, tracing out a triple head spiral path on the shell. The high density of the chain makes it possible to shorten the chain section, thus shortening the drying zone and increasing the calcining zone of the lime kiln. Several pulp mills which have replaced conventional chain sections with a high-density-chain section have reported a fuel consumption decrease of up to 16% combined with a capacity increase of up to 15% (7).

The review of the chain section of the Prince Rupert lime kiln would suggest that the installation of a high-density-chain system would not provide significant energy savings. Additional production capacity could probably be provided by the installation of a high-density-chain section; however, based on the present pulp mill operating rate, additional lime reburning capacity is not required at this time.

Particulate Collection Modifications

Several pulp mills have recently installed high-efficiency electrostatic precipitators to remove particulate matter from the lime kiln exhaust gases. In most cases, the justification for the installation of the precipitator has been an environmental requirement to reduce the particulate emissions and to eliminate the lime kiln stack vapour plume which is commonly associated with dust fallout.

A recent post-start-up evaluation of a lime kiln precipitator installation identified several side benefits and savings not included in the original justification (8). The largest saving was a decrease of purchased lime make-up. Prior to the installation of the precipitator, 50 t/d of lime mud was sewered on a regular basis and purchased lime was used to maintain white liquor production.

The elimination of scrubber recycle resulted in improved lime mud washing and kiln operation. The capacity of the kiln increased and the improved collection efficiency at the precipitator has eliminated the purchased lime make-up requirement, resulting in a net saving of approximately $2.50/ADt of pulp. Although the total fuel consumption has increased with the higher kiln production rate, the specific fuel consumption has decreased by approximately 12% for a potential saving of $0.95/ADt of pulp. In addition, the purchased limestone make-up was reduced by approximately 50% for a saving of $0.25/ADt of pulp. Purchased lime and limestone are now only used during major shut-downs of the lime kiln.

The order-of-magnitude cost of installing a high-efficiency double-chamber precipitator for the Prince Rupert lime kiln has been estimated to be approximately $3,600,000. The potential benefits and savings have been quantified and are presented in Table 3.

Table 3 - Potential Savings for Precipitator

Item	Unit	Amount
Lime rock make-up savings	$/a	3,000
Fuel savings	$/a	12,000
Operating cost savings	$/a	75,000
Heat recovery savings	$/a	320,000
Total Savings	$/a	410,000

The savings in lime rock make-up are based on an improved recovery of lime dust in the lime kiln flue gases. The efficiency of the precipitator has been assumed to be 99.3%, which can be compared to the present scrubber efficiency of 98%. The amount of lime dust recovered at an assumed 8% lime carry-over into the lime kiln flue gases has been estimated to be 270 kg/d or 94.2 t/a.

The existing scrubber is equipped with a wet dust-handling system and the lime slurry is pumped to the lime mud washers and returned to the lime kiln in wet form. The precipitator would be provided with a dry dust-handling system. Therefore, the lime recovered at the precipitator would not have to be dewatered and dried in the lime kiln drying zone. The fuel saving associated with the dry dust-handling system is shown in Table 3.

The operating cost savings are based on the lower power requirement for the precipitator and dry dust-handling system.

The precipitator would be equipped with an flue-gas-to-water heat recovery system. The heat recovery system would be designed to recover 90,000 GJ/a of high-grade heat from the flue gases in the form of 1,500 l/min of 90°C water, which is equivalent to a natural gas saving of 2,300 m^3/a or $320,000 per annum.

Based on the annual savings of $410,000 and an estimated capital cost of $3,600,000, the simple payback would be approximately 8.8 years, which would suggest that this option is not economical for the Prince Rupert lime kiln.

OPTIONS TO REDUCE FUEL COST

General

Three options to reduce the cost of fuel have been identified:

- burning wood waste and hog fuel in the lime kiln
- burning tall oil and tall oil pitch in the lime kiln
- burning turpentine in the lime kiln

The burning of wood waste and hog fuel in the Prince Rupert lime kiln has been considered in this study.

Tall oil, tall oil pitch and turpentine are not available in the wood species in the Prince Rupert area and the recovery of tall oil and crude sulphate turpentine at Prince Rupert would not be economical due to the low soap production and low turpentine yield.

Wood Waste and Hog Fuel Burning in the Lime Kiln

Wood waste and hog fuel are readily available sources of energy at most pulp mills in Canada. The term hog fuel is used in this report to describe the mixture of wood waste, sanderdust, planer shavings, sawdust, forest residue and bark that is prepared and in many cases dried and burned in a boiler to generate steam. The typical moisture content of hog fuel burned in steam boilers is between 30 and 65% by weight on a wet basis. Several systems (10, 11), such as flue-gas and steam dryers, have been developed to reduce the moisture content and increase the heating value of the hog fuel. A definitive study of the various types of dryers was prepared by Sandwell under the ENFOR program (10).

Dried wood waste and hog fuel can also be used to heat the lime kiln. Several pulp mills are presently firing hog fuel in the lime kiln. One pulp mill in Brazil (11) has been operating a hog-fuel-fired lime kiln since January 1983 while another in Sweden (12) has been operating two hog-fuel-fired lime kilns successfully since 1980. The Brazilian unit features a fines-fired dryer while the Swedish unit uses boiler flue gases for direct-contact-heating for drying the hog fuel.

In the Swedish mill the hog fuel, mainly bark, branches, knots and needles, are separated during delimbing and debarking at the woodroom. About 35% of the total biomass material collected at the woodroom is dewatered in a press at the hog fuel handling system and conveyed to the hog fuel drying system. The hog fuel is dried to a moisture content of approximately 10-15% in a flash dryer and used as the primary fuel for the lime kilns. The flash dryer uses boiler flue gases for direct-contact heating for drying the hog fuel.

The hog fuel is screened to remove rocks and metallic material, hogged to a maximum particle size of 100 mm and conveyed to a metering bin. The moist hog fuel enters the drying system through a gas-tight feeder and is mixed with hot boiler flue gases which act as both the transporting and the drying medium. The temperature of the flue gases entering the dryer ranges from 175-250 ^{o}C. The hog fuel is carried by the flue gases through a separator and a pre-drying section under induced draft. The heavy particles are pulverized in a hammermill and the light particles or fines bypass the mill. The pulverized material, with a nominal particle size of approximately 2 mm, goes through a classifier where particles larger than 2 mm are returned to the hammermill. Following the classifier are pressurized vertical cylindrical flash drying flues where the hog fuel is dried to the final dryness (10-15% moisture content) through direct contact between the flue gas and the hog fuel particles. The gas flow can be maintained at the required rate by recirculating part of the flue gases. The dried hog fuel is separated in a cyclone and discharged into a surge bin having a capacity of approximately ½ to 1 hour.

The hog fuel is discharged from the surge bin by screw feeders and blown to the lime kiln burner using primary combustion air. The dried hog fuel can be fired in the kiln without supporting fuel because the glowing refractory helps to support combustion. Oil or natural gas is used during kiln start-up and in a pilot role during upset operating conditions. Combustion of pulverized and dried hog fuel of about 15% moisture content will generate a temperature of about 1,450 ^{o}C which is sufficient to reach the calcination temperature of the lime. The lime kiln flame shape is influenced by the velocity and the temperature of the primary air and more significantly, the particle size distribution when

firing hog fuel in the lime kiln. If the particles are too small, the combustion will take place too soon resulting in a short flame and potential localized overheating and damage to the kiln refractory. Oversized particles can cause incomplete combustion and increased deadload in the recausticizing cycle.

The performance of the hog-fuel-fired lime kilns has generally been very good. Some problems were experienced with the lime kiln burner during the first year of operation in the Swedish mill (13). The flame shape was difficult to control with the original burner. Variations in fuel flow caused puffs in the combustion zone and the high air velocity tended to move the combustion zone away from the ideal location. The design of the burner was modified and the installation of the modified burner solved the problems with the flame shape and eliminated the puffs.

The flame temperature is lower for the hog-fuel-fired lime kilns than for oil-fired kilns, requiring a longer heating and calcining zone. This can be partly compensated for by increasing the fuel flow and shortening the drying zone in the lime kiln.

The lime quality has been maintained with laboratory tests suggesting an increase in the reactivity and a decrease in the sedimentation rate. The quality of the white liquor has not changed and the apparent reduction in the settling rate has not resulted in increased lime mud carry-over into the white liquor. The colour of the reburned lime produced by the hog-fuel-fired lime kilns has changed from a grayish colour to a yellow-brownish colour.

The flue gas scrubber recycle liquid, with a dregs content of approximately 15 g/l or 15,000 ppm, is returned to the dregs washer in the recausticizing department and this caused an abnormal carry-over of dregs into the green liquor system during the first year of operation. The green liquor clarifiers were operated at approximately 40-50% above design capacity. A new green liquor clarifier was installed in 1982 which improved the green liquor clarity from 200-400 ppm to 25-50 ppm. The problems with carry-over of dregs were reduced and the overall operation in the recausticizing department has stabilized. Further work is planned to eliminate the dregs problem caused by the flue gas scrubber recycle.

Again, in the Swedish mill, shortly after start-up of the hog fuel drying systems, it was noted that the scaling of the multiple-effect evaporators had increased. The scaling was believed to have been caused by aluminum and silicon compounds, which enter the kraft process with the wood, the make-up lime and peat fuel used in the power boiler. Two modifications have been implemented which have reduced the problem. Firstly, the cross-over of high silicon and aluminum ash from the peat-fuel drying system into the hog-fuel drying system has been eliminated. The original design of the two drying systems was based on a common flue gas circulation loop. This allowed for an uncontrolled cross-over of dust and ash particles into the hog fuel flue gas system. Secondly, the improved lime kiln burner system has reduced the periods of high purchased lime consumption. A significant amount of silicon and aluminum compounds enters with the make-up lime. This component is now maintained within a manageable level. The problem with evaporator scaling has not been entirely eliminated but the modifications made to the peat and hog fuel drying systems and the lime kilns have minimized the problem. The mill reports that the evaporator scaling problem is now manageable and close to the experience prior to the start-up of the peat and hog fuel drying systems.

A process has been developed to remove aluminum from the green liquor system. This process was tried in a pilot plant at the mill with partial success. Further work is planned

to refine this process and a full-scale installation may be installed, should the evaporator scaling problem become unmanageable.

The installation of a hog fuel drying system to dry hog fuel for the Prince Rupert lime kiln would provide significant savings in fuel cost. The energy balance for this option has been summarized in Appendix 4. The potential fuel savings are summarized in Table 4.

Table 4 - Economics of Burning Hog Fuel in the Lime Kiln

Item	Unit	Amount
Lime kiln heat consumption	GJ/t CaO	7.7
Gross heating value of hog fuel	MJ/ODkg	20.5
Hog fuel consumption	ODkg/t CaO	375
	ODt/d	87
Fuel cost - natural gas	$/t CaO	27.10
	$/a	2,180,000
- hog fuel	$/t CaO	6.60
	$/a	530,000
Fuel saving $/a		1,650,000
Fuel cost to dry hog fuel	$/a	100,000
Fuel cost during hog fuel dryer maintenance	$/a	250,000
Net fuel saving $/a		1,300,000

The major components of the drying system are:

- wet fuel storage bin and feeder
- inlet air-lock feeder
- pre-dryer
- hammermill
- classifier and separator
- flash drying flues
- cyclone separator and discharge feeder
- induced draft fan
- dry fuel storage bin and feeder
- outlet air-lock feeder
- cooling stage for dried fuel
- dry fuel handling system
- lime kiln burner system

A simplified flow diagram for the hog fuel dryer has been included in Appendix 6.

The amount of hog fuel required to heat the Prince Rupert lime kiln has been estimated to be approximately 87 ODt/d. Some of the hog fuel could be obtained from existing sources, presently supplying low cost hog fuel to the steam generating power boiler. However, the economics are based on transporting the total amount of hog fuel required to the mill site from local sawmills at a cost of $17.50/ODt. The availability of hog fuel

has not been confirmed in this study but will be investigated during the preliminary engineering phase of the project.

The heat for drying the hog fuel can be provided by boiler flue gases, lime kiln exhaust gases or by indirect steam heating or direct heating of the dryer circulation air. The savings in Table 4 are based on indirect heating of the hog fuel dryer air with natural gas. A more cost-effective system would employ either the flue gases from the kiln, or a portion of the dried hog fuel which would be fired in a separately-fired dryer; these options are discussed below.

The capital cost to install a hog fuel drying system for the Prince Rupert "A"-mill lime kiln has been estimated to be approximately $3,000,000.

Based on the capital cost of $3,000,00 and the potential savings of $1,300,000 per annum, as shown in Table 4, the simple payback would be approximately 2.3 years, which would suggest that the installation of a hog fuel drying system for the Prince Rupert lime kiln is economical and should be considered in the program to reduce the fuel cost for the lime kiln. The availability of hog fuel and the perhaps-attractive competing possibility of firing pulverized hog fuel in the power boiler would require to be evaluated. If the heat required at the hog fuel dryer is provided by the lime kiln exhaust gases, then the savings in Table 4 would increase to approximately $1,400,000 and the payback period would decrease to 2.1 years. The feasibility of using the lime kiln exhaust gases or a hog-fuel-fines burner to heat the hog fuel dryer will be investigated during the preliminary engineering phase of the project.

Tall-oil-burning in the Lime Kiln

Tall oil or crude tall oil (CTO) is produced from soap skimmings recovered from the black liquor in the kraft pulping process. In many mills with low CTO potential, the soap is left in the black liquor and the heat value is partially recovered as part of the energy generated by firing the black liquor in the recovery boiler. The market price for CTO changes with the overall availability of petroleum-based feedstocks for the chemical industry, which in recent years has caused difficulties for major CTO distillers, forcing down the price of CTO. This situation has forced mills with a considerable CTO production to search for alternative markets and uses for the CTO. One option that is available to most pulp mills is to burn the CTO in a steam boiler or in the lime kiln (14).

The typical gross heating value of crude tall oil has been determined to be 35-40 MJ/kg, which is lower than the typical 40-45 MJ/kg heat value for heavy fuel oil. Operating experience from mills, where CTO has been mixed with heavy fuel oil for firing in steam boilers and lime kilns would suggest no major problems with mixing the two fuels. One mill has operated a lime kiln for several years on a fuel with up to 60% CTO mixed with the heavy fuel oil (14). CTO is presently successfully being fired as auxiliary fuel in the lime kiln in several pulp mills world wide.

The amount of tall oil produced by Canadian pulp mill operations varies with the wood species used in the pulping process. For example, interior mills in British Columbia can produce up to 20 kg CTO/ADt of pulp, whereas the amount of soap produced by the coastal British Columbian mills is too low to permit economical CTO production. If a mill can produce 20 kg/ADt of pulp and burn the CTO in the lime kiln, then the CTO would provide about 25% of the total heat input required at the lime kiln or approximately 2.3 GJ/t CaO.

Tall oil is not an economical fuel if the CTO can be sold at regular market prices. The tall oil market, however, is volatile and rapid changes in the price of CTO are common.

If the CTO can not be sold at the market price, then the savings from burning CTO in the lime kiln would be $880,000 per annum if fuel oil were used in the kiln and $650,000 per annum if natural gas were used.

However, these savings are not applicable to the Prince Rupert lime kiln operation as the amount of soap produced from the type of wood species used in the kraft pulping process would not yield economical quantities of CTO if collected and processed.

The potential fuel savings have been summarized in Table 5 below.

Table 5 - Potential Fuel Savings

Item	Unit	Amount
CTO production	kg/ADt	20
CTO market value	$/t	190
	$/a	1,000,000
CTO gross heating value	MJ/kg	35
	GJ/t CaO	2.3
Fuel savings:		
- Natural gas	MJ/m^3	38.4
	m^3/t CaO	60
	$/t CaO	10
	$/a	650,000
Net saving, gas	$/a	(350,000)
- Fuel oil	GJ/m^3	57
	l/t CaO	40
	$/t CaO	11
	$/a	880,000
Net saving, oil	$/a	(120,000)

In addition to tall oil or CTO, several mills are also mixing tall oil pitch (TOP) with heavy fuel oil for use as fuel for the lime kiln (15, 16). TOP contains mainly low-volatile compounds such as fatty acids and resin acids and is a waste product of the tall oil refining process. The very steep viscosity curve of TOP is caused by the high proportion of resin acids. Due to the high viscosity, TOP must be preheated to about 110°C prior to handling and mixing with fuel oil. TOP is an excellent fuel with a gross heating value of 40 MJ/kg.

After some initial problems with the TOP handling systems, several pulp mills are now burning TOP mixed with fuel oil in the lime kiln; one mill has averaged up to 35% of the total heat input from TOP.

The potential savings would depend on the availability of TOP within an economical transportation distance of the pulp mill. TOP is not readily available in British Columbia and has therefore not been considered as an alternative fuel in this study.

Turpentine-burning in the Lime Kiln

Turpentine is a waste product in the kraft pulping process and is recovered at the digester from the non-condensible relief gases. The relief gases are condensed in a surface condenser and cooled in a gas cooler and the crude sulphate turpentine is separated from aqueous condensate in a decanter. The turpentine recovery system is maintained in a steady state operating mode with the flow rate determined by the digester plant operating rate.

Most Canadian mills using softwood species in the kraft pulping process operate turpentine recovery systems. Typical turpentine production rates reported by eastern Canadian and interior B.C. mills are between 3 and 6 l/ADt of pulp. If the turpentine were used as fuel for the lime kiln, it would provide about 5% of the total heat input at the lime kiln.

The most common method of burning turpentine in the lime kiln is to mix the turpentine with heavy fuel oil. Several Canadian mills are successfully burning turpentine in the lime kiln and no problems have been reported with the kiln operation or the lime quality.

The economics of burning turpentine in the lime kiln has been summarized in Table 6.

Table 6 - Economics of Burning Turpentine in the Lime Kiln

Item	Unit	Amount
Turpentine production	l/ADt	3
Turpentine market value	$/l	0.15
	$/t CaO	1.50
Turpentine gross heating value	MJ/l	40
	GJ/t CaO	0.4
Fuel savings:		
- Eqv. natural gas	MJ/m^3	38.4
	m^3/t CaO	10.3
	$/t CaO	1.40
Net saving	$/t CaO	(0.10)
- Eqv. fuel oil	MJ/l	57
	l/t CaO	7
	$/t CaO	1.90
Net saving	$/t CaO	0.40

The burning of turpentine is not economical if natural gas is used as the primary fuel in the lime kiln and there is a market for the turpentine within an economical transportation distance of the pulp mill. However, if heavy fuel oil is used in the lime kiln, then the potential saving would be approximately $0.40/t CaO or $32,000 per annum at a pulp production of 750 AD/t. The saving would increase to approximately $150,000 per annum if a market for turpentine were not available.

As with tall oil, the turpentine production at the Prince Rupert mill is not sufficient to justify a turpentine collection system; therefore the above savings are not applicable to the Prince Rupert operation and have not been considered in this study.

PROJECT ENGINEERING PLAN AND IMPLEMENTATION PROGRAM

Engineering Plan

The proposed engineering plan for the demonstration project would be implemented in three phases:

Phase I - Preliminary engineering
Phase II - Design development
Phase III - Detailed design

The detailed description of the proposed engineering plan is contained in Appendix 5 of this report.

Implementation Program

The proposed program includes the following modifications, either physical or operational, and additions to the existing lime kiln at Prince Rupert:

- increased retention time in the lime kiln calcining zone
- painting of the lime kiln shell at the calcining zone and installation of a cover over the lime kiln
- installation of a hog fuel preparation and drying system to pulverize and dry wood fibre fuel, suitable for firing in the lime kiln

The installation of a high-efficiency electrostatic precipitator for the Prince Rupert lime kiln does not appear to be attractive at this time; however, the economics and environmental benefits would be reviewed during the proposed preliminary engineering phase of the project. The investigations would include an evaluation of the possibility of utilizing the lime kiln flue gases for drying the hog fuel and integrating the precipitator into the hog fuel drying system. The overall benefits may provide sufficient savings to justify the installation of a high-efficiency precipitator in conjunction with a hog fuel drying system.

Program Costs

The capital costs for the proposed program of modifications and additions to improve the energy efficiency of the Prince Rupert lime kiln have been summarized in Table 7.

Table 7 - Capital Cost Summary

Item	Cost - $
Increased lime kiln retention time	3,000
Painting of lime kiln	260,000
Hog fuel drying system	3,000,000
Total capital cost	$3,263,000

The estimated costs for the multi-phase engineering plan have been summarized in Table 8.

Table 8 - Summary of Engineering Costs

Item		Manhours	Cost - $
Phase I	- Preliminary engineering	650	36,000
Phase II	- Design development	1,600	85,000
Phase III	- Detailed design	9,500	475,000
Total		11,750	596,000

CONCLUSIONS

1. The energy consumption of the Prince Rupert "A"-mill lime kiln has been calculated to be 8.4 GJ/t CaO. The calculated consumption is significantly higher than the measured fuel consumption of 6.9 GJ/t CaO. The difference between the measured and the calculated energy consumption is probably related to the conversion factor used to calculate the lime kiln fuel consumption.

2. The "A"-mill lime kiln operation is very energy efficient and the calculated fuel consumption compares favourably with similar size Scandinavian lime kilns, which are generally considered to be among the most energy-efficient in the world.

3. The thermal efficiency of the lime kiln can be improved by:

   - reducing the calcining temperature and increasing the lime kiln retention time
   - reducing the radiation and convection loss at the lime kiln
   - improving the particulate collection efficiency and providing a dry dust collection system

4. The lime kiln fuel consumption can be reduced by approximately 1% by reducing the calcining zone temperature from 1,060°C to 1,000°C. The lime kiln retention time should be increased by 5-10 min to compensate for the lower calcining temperature. The capital cost to increase the height of the front-end dam in the lime kiln has been estimated to be $3,000. The savings associated with this modification have been estimated to be approximately $14,000 per annum or $0.05/ADt of pulp for the Prince Rupert "A" mill.

5. The lime kiln radiation and convection losses can be reduced by approximately 30% by the installation of a wind shelter, by painting of the lime kiln hot end and by increasing the lime kiln refractory lining to the original design thickness. The capital cost of these modifications has been estimated to be $260,000. The fuel saving associated with the modifications has been calculated to be approximately 10%, which corresponds to an annual saving of approximately $200,000 or $0.75/Adt of pulp, for the Prince Rupert "A" Mill.

6. The existing lime kiln chain section, product coolers and fuel burner are performing well and any modifications to the existing equipment would not provide significant energy efficiency improvements.

7. The particulate collection efficiency can be improved by installing a high-efficiency electrostatic precipitator to remove particulate from the lime kiln exhaust gases.

The capital cost for the precipitator has been estimated to be $3,600,000. The precipitator would provide operating cost savings of approximately $410,000 per annum or $1.55/ADt of pulp for the "A"-mill. The installation of a high-efficiency precipitator may not be economical; however, the environmental benefits would be significant, particularly if the precipitator were installed in conjunction with a hog fuel dryer.

8. The purchased fuel consumption can be reduced by installing a hog fuel dryer. The capital cost for a hog fuel dryer, sized to provide 100% of the heat required for the lime kiln, has been estimated to be approximately $3,000,000. The net fuel saving associated with the hog fuel dryer has been estimated to be approximately $1,300,000 per annum or $4.90/ADt of pulp for the "A"-mill at Prince Rupert.

9. Other alternative fuels, such tall oil, tall oil pitch and turpentine, can be used in the lime kiln. However, these fuels are not available in the Prince Rupert area.

10. The proposed engineering plan would consist of three phases:

    Phase I - Preliminary Engineering
    Phase II - Design Development
    Phase III - Detailed Design

11. The implementation program would include the following modifications and additions:

    - modifications to increase the lime kiln retention time
    - modifications to reduce the lime kiln radiation and convection losses
    - installation of a hog fuel dryer

12. The capital costs for the proposed modifications and additions have been estimated to be approximately $3,300,000. The energy and fuel savings associated with the modifications have been estimated to be approximately $1,500,000 per annum or $5.60/ADt of pulp for the "A"-mill at Prince Rupert.

13. The energy and fuel savings are attractive and the proposed modifications and additions could form a base for a demonstration project to optimize an existing lime kiln operation and significantly reduce the consumption of fossil fuel.

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APPENDIX 1

GLOSSARY

LIME KILN OPTIMIZATION

APPENDIX 1 - GLOSSARY

a	-	Annum
A	-	Ampere
ADt	-	Air Dry Tonne (1,000 kg)
CTO	-	Crude Tall Oil
d	-	Day
dia	-	Diameter
F.D.	-	Forced draft
g	-	Gram
GJ	-	Gigajoule
I.D.	-	Induced draft
kg	-	Kilogram
kJ	-	Kilojoule
kPa	-	Kilopascal
kW	-	Kilowatt
l	-	Litre
L	-	Length
m	-	Meter
mm	-	Millimetre
m^3	-	Cubic metre
min	-	Minute
MJ	-	Megajoule
ODt	-	Oven Dry Tonne (1000 kg)
Pa	-	Pascal
ppm	-	Parts per Million
rpm	-	Revolutions per Minute
t	-	Tonne (1,000 kg)
TOP	-	Tall Oil Pitch
^oC	-	Degree Celsius
CaO	-	Calcium Oxide
$CaCO_3$	-	Calcium Carbonate
CO_2	-	Carbon Dioxide
$	-	Canadian Dollar
%	-	Percent

APPENDIX 2

LIME KILN DESIGN DATA

REPORT V6669/1
DEPT. OF ENERGY, MINES AND RESOURCES
CANMET, ENERGY RESEARCH LABORATORIES

GOVERNMENT OF CANADA
DEPT. OF SUPPLY AND SERVICES
HULL QUEBEC

DATE 17 AUGUST 1984

PRE-ENGINEERING ASSESSMENT OF
ENERSOLVE DEMONSTRATION PROJECT

LIME KILN OPTIMIZATION

APPENDIX 2 - LIME KILN DESIGN DATA

INTRODUCTION

The design data for the lime kiln and auxiliary equipment at the Westar pulp mill at Prince Rupert are summarized in Table 1.

Table 1 - Lime Kiln System Design Data

Item	Unit	Amount
Size, dia x L	m x m	3.7x 99
Refactory lining		
- design	mm	230
- presently installed	mm	150
Length to diameter ratio		31:1
Design capacity	t CaO/d	215
Inclination of shell	mm/mm	1:27.5
Kiln speed - maximum	rpm	1.25
- normal	rpm	1.1
Chain system:		
- Size, chain diameter	mm	16.0
- Linear length of chain	m	5,200
- Length of chain section	m	15
Product coolers:		
- Type		Planetary
- Manufacturer		Warner
- No. of coolers		8
- Size, dia x L	m	1.2 x 4.0
- Heat removal capacity	kJ/t CaO	525,000

Table 1 - Lime Kiln System Design Data (continued)

Item	Unit	Amount
Primary air fan:		
- Capacity	m^3	255
- Type of drive		V - belt
- Speed	rpm	1750
- Motor	kW	30
- Pressure drop at 70°C	Pa	3.5
Induced draft fan:		
- Capacity	m^3	2,400
- Type of Drive		V - belt
- Speed	rpm	1200
- Motor	kW	250
- Pressure drop at 254°C	Pa	4.5
Kiln burner:		
- Type		Water-jacketted, mechanical atomizer
- Make		Peabody
- Size		No. 6
Design fuel consumption:		
- at 0 km/h wind velocity	kJ/t CaO	6,950,000
- at 10 km/h wind velocity	kJ/t CaO	7,700,000
- at 25 km/h wind velocity	kJ/t CaO	8,500,000
Venturi Scrubber:		
- Type		Wet Venturi
- Design capacity at 254°C and 94.7 kPa	m^3	920
- Pressure drop - venturi	Pa	3.2
- separator	Pa	0.5
- Liquid rate at 7 to 14 kPa	l/min	1900 to 2650
- Scrubber efficiency	%	98

APPENDIX 3

FUEL SPECIFICATIONS AND OPERATING STATISTICS

REPORT V6669/1
DEPT. OF ENERGY, MINES AND RESOURCES
CANMET, ENERGY RESEARCH LABORATORIES

GOVERNMENT OF CANADA
DEPT. OF SUPPLY AND SERVICES
HULL QUEBEC

PRE-ENGINEERING ASSESSMENT OF
ENERSOLVE DEMONSTRATION PROJECT

DATE 17 AUGUST 1984

LIME KILN OPTIMIZATION

APPENDIX 3 - FUEL SPECIFICATIONS AND OPERATING STATISTICS

INTRODUCTION

The heat values of the various fuels available at Prince Rupert and some other alternative fuels have been summarized in Table 1. These heat values were used in the calculations of consumptions and energy savings.

The costs of the various fuels and raw materials used in the calculations have been summarized in Table 2.

The natural gas and make-up chemical consumptions have been summarized in Table 3.

The lime kiln operating statistics collected during the site visit have been summarized in Table 4 and Table 5. The data in Table 4 were recorded during the site visit on 1 and 2 of May 1984. Table 5 presents the daily average operating statistics for the month of November 1983.

Table 1 - Gross Heating Values of Fuels

Item	Unit	Amount
Natural gas	MJ/m^3	38.4
Fuel oil No. 6	MJ/l	57
Hog fuel	MJ/ODkg	20.5
Crude tall oil (CTO)	MJ/kg	35-40
Tall oil pitch (TOP)	MJ/kg	40
Turpentine	MJ/kg	9.5

Table 2 - Fuel and Make-up Chemical Costs

Item	Unit	Amount
Natural gas	$\$/m^3$	0.135
Fuel oil No. 6	$\$/m^3$	271
Hog fuel	\$/ODt	17.50
Make-up purchased lime	\$/t	167.4
Make-up lime rock	\$/t	23.0

Table 3 - Natural Gas and Make-up Chemical Consumptions

Item	Unit	Amount
Natural gas:		
- Measured avg. consumption	m^3/t CaO	136
- Est. actual consumption	m^3/t CaO	175
Make-up lime rock (1983)	kg/ADt	15
Make-up purchased lime (1983)	kg/ADt	0

Table 4 - Operating Statistics for 1 and 2 of May 1984

Item	Unit	Amount
Average lime production	t/d	222
- Equiv. mud production	t/d	396
Mud flow	l/min	810 - 870
Mud solids	%	30 -31
Mud density		1.22
Natural gas flow	m^3/min	40.8
Cold-end temperature	°C	260
Hot-end temperature	°C	1065
Back-end pressure	Pa	-8.7 to -11.2
Front-end pressure	Pa	-6.2 to -11.2
Oxygen	%	3.4 - 9.6*
F.D. damper	%	30-50
I.D. damper	%	95
I.D. fan power	A	270
Primary air flow	%	23-47
Exhaust air flow	%	63
Kiln speed	rpm	1.13

*The oxygen concentration is measured at the feed-end housing of the lime kiln. The target level is 1-2%. The above readings were recorded during an 8 hour period of relatively unstable kiln operation.

Table 5 - Operating Statistics for November 1983

Day	Natural Gas Flow %	Temperature Cold End °C	Temperature Hot End °C	Drafts Front End Pa	Drafts Back End Pa	Gas Flows Primary Air %	Gas Flows Exhaust Air %	Oxygen %	Speed rpm	Lime Production t/d	Pulp Production ADt/d
1	50	265	1056	-9	-6	39	72	2.8	1.25	222	816
2	48	289	1036	-5	-1.5	38	70	1.8	1.25	211	807
3	66	270	1043	-6	-3	32	73	1.5	1.25	239	849
4	58	266	1064	-8	-3.5	32	76	1.4	1.25	239	837
5	55	274	1057	-6	-2.5	37	76	1.8	1.25	241	871
6	50	273	1057	-6	-2.2	40	78	2.2	1.25	246	755
7	49	263	1054	-6	-2	38	86	3.2	1.2	250	770
8	42	270	1067	-5	-1.2	41	89	3.7	1.15	225	671
9	47	315	1072	-5	-2.2	46	42	3.5	1.2	180	531
10	47	271	1029	-5	-2	36	48	1.8	1.2	222	826
11	44	281	1065	-5	-2	32	49	2.0	1.25	224	853
12	47	288	1048	-4.5	-1.2	31	32	1.1	1.1	224	519
13	39	260	1073	-5.5	-1.7	34	76	2.1	1.25	219	719
14	47	263	1071	-5	-1	38	78	2.0	1.25	230	851
15	47	251	1074	-4.5	-1	34	65	1.3	1.22	224	792
16	48	265	1079	-5	-1.2	31	72	1.5	1.25	226	873
17	29	281	1019	-3.5	-1	31	34	5.0	1.14	207	381
18	38	280	1067	-5	-1	37	57	2.0	1.25	235	727
19	40	257	1064	-5	-0.8	45	60	2.5	1.25	241	692
20	33	247	1058	-4.5	-1.2	35	56	3.1	1.18	238	742
21	39	252	1076	-6.5	-2.5	43	56	2.0	1.2	215	875
22	63	266	1039	-5.5	-1.7	33	66	0.7	1.25	259	682
23	48	297	1029	-7.5	-2	32	61	1.3	1.25	245	657
24	50	289	1068	-7	-2.2	33	66	0.9	1.25	232	779
25	49	255	1036	-7	-2.2	37	62	0.9	1.25	234	791
26	55	275	1008	-4	-0.8	36	62	0.8	1.25	254	724
27	45	294	1086	-4.5	-0.8	36	38	0.9	1.16	238	859
28	44	285	1073	-4	-0.5	37	64	1.1	1.18	245	817
29	48	293	1080	-5	-0.5	34	81	0.9	1.25	239	837
30	53	278	1072	-5	-0.8	30	71	0.6	1.05	220	869
Avg.	47	274	1057	-5.5	-1.7	36	64	1.9	1.21	230	760

(V6669/1, App.3)

APPENDIX 4

LIME KILN MATERIAL AND ENERGY BALANCES

REPORT V6669/1
DEPT. OF ENERGY, MINES AND RESOURCES
CANMET, ENERGY RESEARCH LABORATORIES

GOVERNMENT OF CANADA
DEPT. OF SUPPLY AND SERVICES
HULL QUEBEC

PRE-ENGINEERING ASSESSMENT OF
ENERSOLVE DEMONSTRATION PROJECT

DATE 17 AUGUST 1984

LIME KILN OPTIMIZATION

APPENDIX 4 - LIME KILN MATERIAL AND ENERGY BALANCES

The stream numbers in the following tables refer to the attached simplified lime kiln flow diagram.

The operating parameters common to all material balances have been summarized in Table 1.

Table 1 - Mill Operating Parameters

Item	Unit	Amount
Pulp production	Adt/d	760
Lime kiln production	t CaO/d	230
Lime rock make-up	kg/ADt	15
Lime availability	%	90
Lime mud moisture	%	30
Ambient temperature[1].	^{o}C	21
Natural gas gross heating value	MJ/m^3	38.4
Hog fuel moisture content	%	63
Hog fuel gross heating value	MJ/ODkg	20.5

Note:

1. The "A"-mill kiln at Prince Rupert is housed around the planetary coolers and 20 ft past them. For simplicity however, a single ambient temperature has been employed.

Lime kiln material balances for the present operation and the various options are summarized in Table 2.

Table 2 - Material Balances, kg/t of Lime Kiln Product

Stream Number[1.]	Material	Present Condition Input-kg/t	Hog Fuel Burning Input-kg/t
1	Lime mud	1,720	1,720
1	Inerts	100	100
1	Water	740	740
2	Lime rock make-up	50	50
3	Natural gas	130	(17)[2.]
3	Hog fuel	-	400 (350)[2.]
3	Water		65
4	Non condensible gas	60	60
5	Primary air	750	1,700
6	Secondary air	2,080	1,690
	Total Input	5,630	6,525
7	Lime (CaO)	900	900
7	Inerts	100	100
8	Combination gases	3,020	3,850
8	CO_2	780	780
8	Water vapour	740	805
8	Stack loss	2	2
9	Scrubber/precipitator loss	88	88
	Total Output	5,630	6,525

Notes:

1. - Refers to Figure 4-1 Lime kiln material and heat balance diagram.
2. - Annual average. Natural gas normally zero.

The lime kiln heat balances for the present operating conditions and the various options are summarized in Table 3.

Table 3 - Heat Balances, MJ/t of Lime Kiln Production

Stream Number[1.]	Energy Source	Present Condition	Increased Retention Time	Reduced Radiation Loss	Hog Fuel Burning
		Amounts			
	Input - MJ/t				
1	Lime mud	70	70	70	70
1	Water	140	140	140	140
3	Natural gas	6,735	6,685	6,035	(890)[2.]
3	Hog fuel	-	-	-	7,720 (6,830)[2.]
3	Non-condensible Gases	1,635	1,635	1,635	1,635
	Total Input	8,580	8,530	7,880	9,565
	Output - MJ/t				
7	Lime	115	115	115	115
8	Lime decomposition	2,900	2,900	2,900	2,900
8	Carbon dioxide	150	140	150	150
8	Water				
	- Heating	105	105	105	105
	- Evaporation	1,635	1,635	1,635	1,635
	- Superheat	245	230	245	245
8	Combustion gases				
	- Natural gas	1,325	1,320	1,175	-
	- Hog fuel	-	-	-	2,310
	- Non-condensible gases	325	310	325	325
9	Scrubber solids	20	15	20	20
9	Precipitator solids	-	-	-	-
10	Radiation loss	1,760	1,760	1,210	1,760
	Total Output	8,580	8,530	7,880	9,565

Notes:

1. - Refers to Figure 4-1 Lime kiln material and heat balance diagram.
2. - Annual average. Natural gas normally zero.

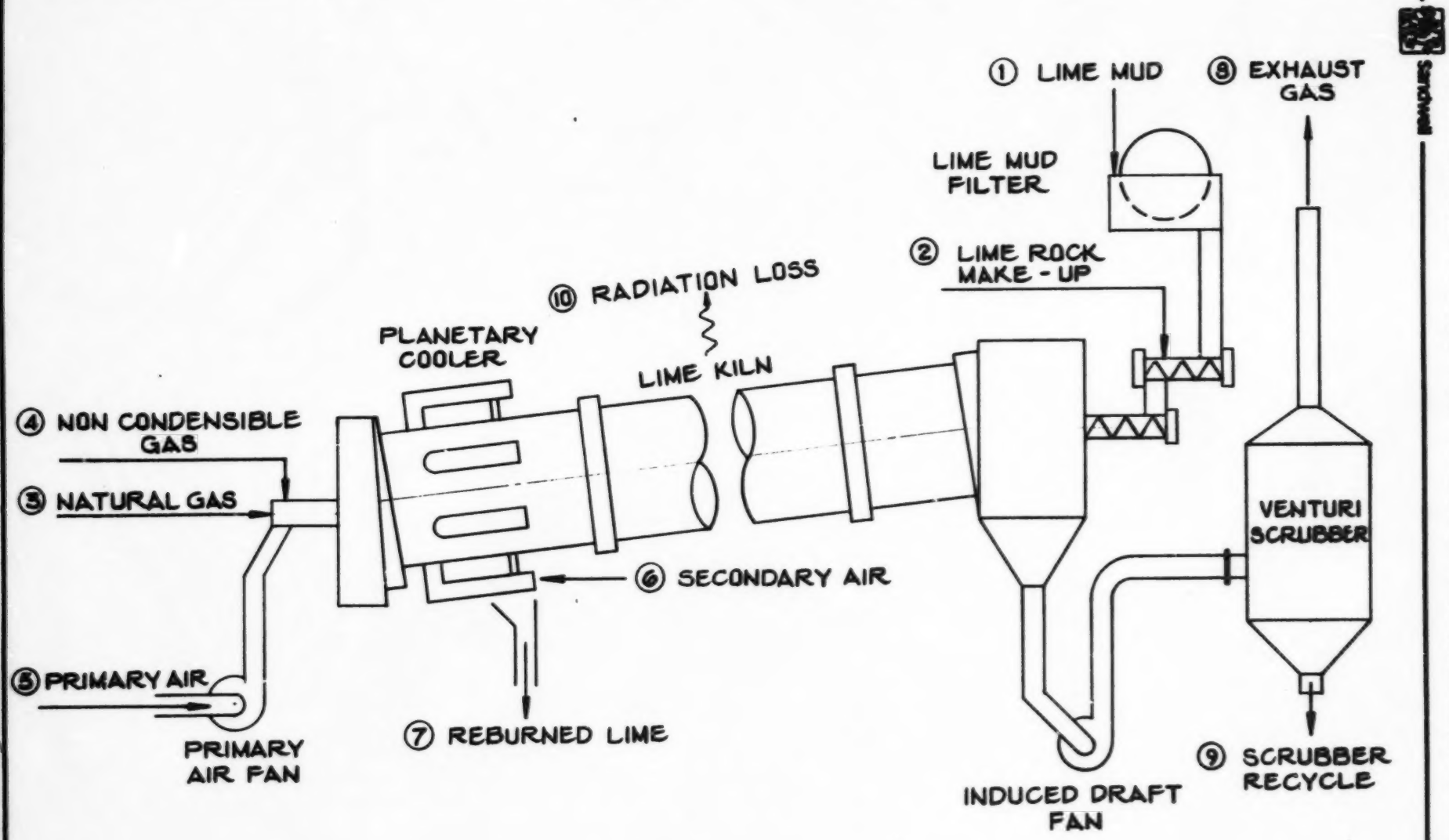

FIGURE 4-1

LIME KILN MATERIAL AND HEAT BALANCE

(VG669/1, APP. 4)

APPENDIX 5

ENGINEERING PLAN

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LIME KILN OPTIMIZATION

APPENDIX 5 - ENGINEERING PLAN

General

The proposed engineering plan would be implemented in three phases:

Phase I - Preliminary Engineering
Phase II - Design Development
Phase III - Detailed Engineering

Phase I - Preliminary Engineering

Phase I - Preliminary Engineering would include the following items:

- a detailed review of the existing lime kiln operation, including field tests to determine actual flow rates and operating temperatures such as the flue gas, kiln shell, reburned lime and lime mud feed temperatures

- confirmation of the potential savings identified in this report, including a review of the economics of the proposed modifications and additions

- confirmation of the material and heat balances using actual measurements of the lime kiln temperatures and flow rates

- preparation of detailed design criteria for the existing lime kiln operation, based on actual lime kiln operating rates

The results of the Phase I review would be presented in an engineering report, which would include detailed material and heat balances based on the actual lime kiln operating rates.

Sandwell estimates that the Phase I work - Preliminary Design, would require approximately 650 engineering manhours.

Phase II - Design Development

Phase II - Design Development would include the following items:

- preparation of preliminary engineering flowsheets and general arrangement drawings

- preparation of detailed design criteria

- preliminary civil and structural design

- preliminary electrical and process control design
- preparation of preliminary specifications for major equipment
- procurement of budget costs for major equipment
- estimation of equipment costs and installation labour for the proposed modifications and additions
- preparation of a construction budget for the proposed modifications
- preparation of a preliminary engineering and construction schedule

The results of the Phase II work would be presented in a report, which would include detailed design criteria, an itemized construction budget, flowsheets and general arrangement drawings.

The Phase II work - Design development, has been estimated by Sandwell to require approximately 1,600 manhours.

Phase III - Detailed Design

The Phase III - Detailed Design would include the following items:

- finalization of material and heat balances for the modified lime kiln system
- finalization of detailed design criteria
- preparation of engineering flowsheets and general arrangement drawings
- civil and structural design
- electrical and process control design
- preparation of equipment specifications
- issue of price inquiries, evaluation of bids and placement of purchase orders for all major equipment
- preparation of installation contract specifications, issue for tender and award of construction contracts
- preparation of engineering and construction schedules
- project management, cost control, scheduling, construction, supervision and start-up assistance

The Phase III work - Detailed Design, has been estimated to require approximately 9,500 manhours.

APPENDIX 6

ILLUSTRATIONS

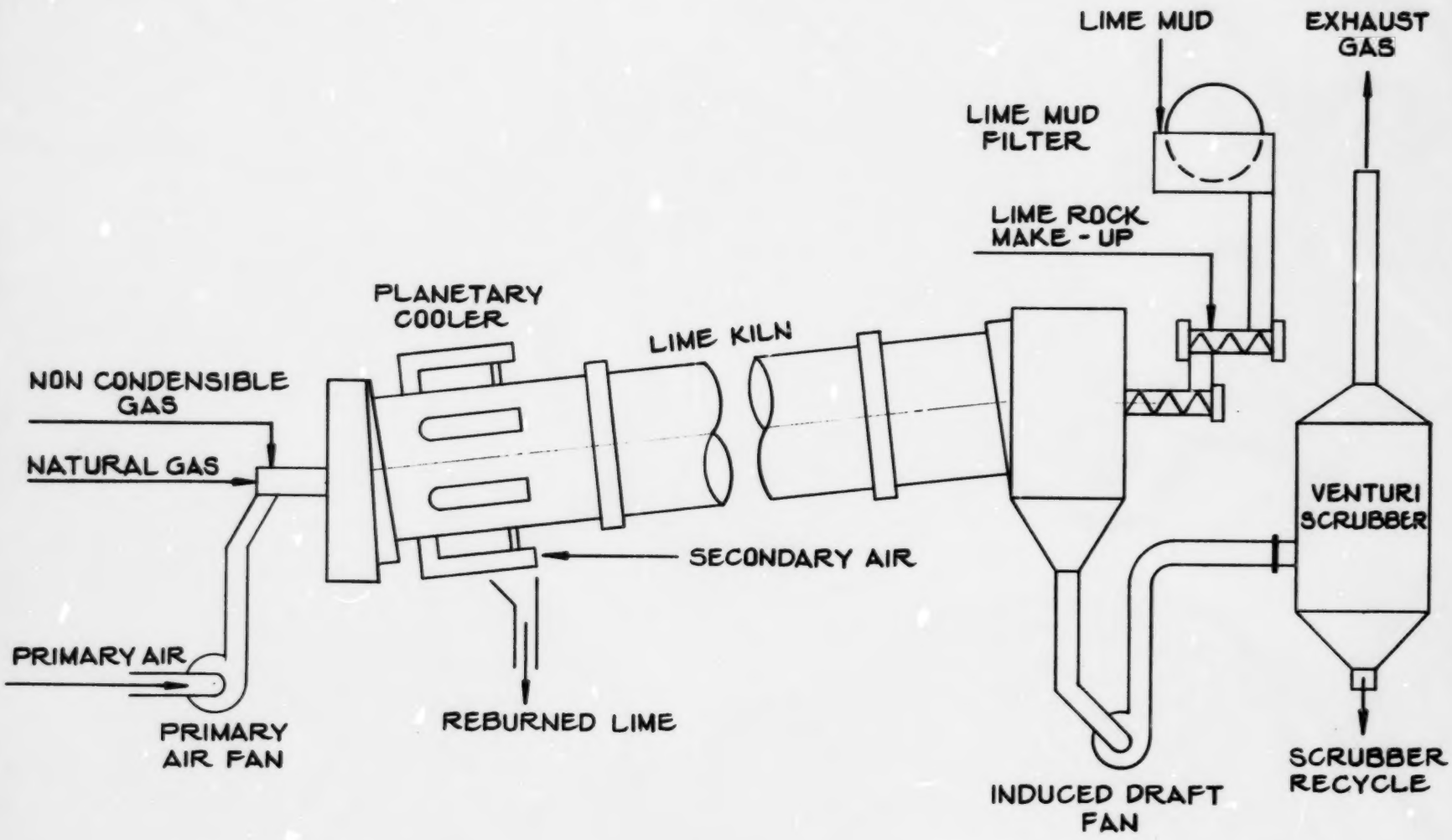

FIGURE 6 - 1

SIMPLIFIED LIME KILN DIAGRAM

(V6669/1, APP. 6)

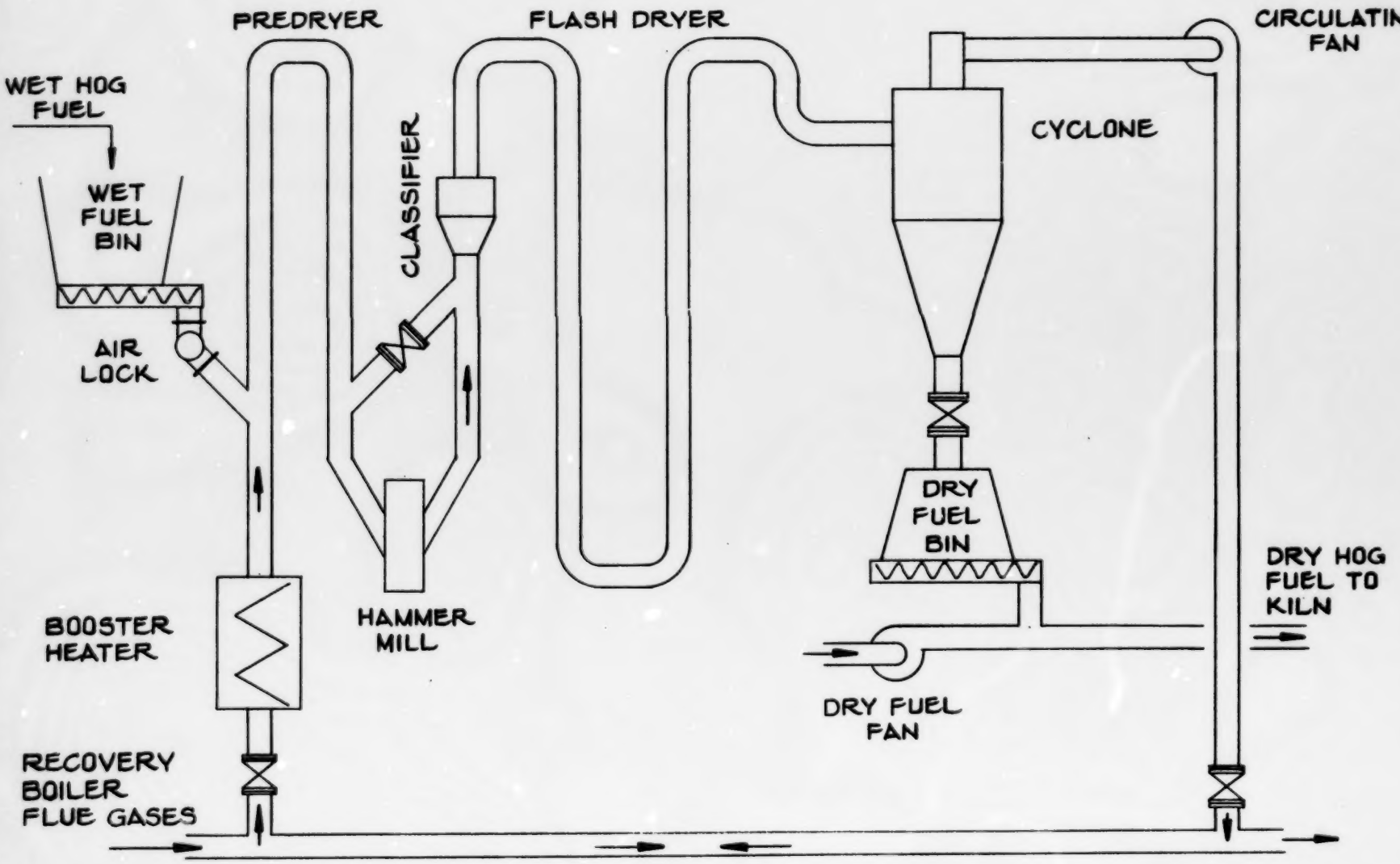

FIGURE 6 - 2

SIMPLIFIED HOG FUEL DRYER DIAGRAM

(V6669/1, APP. 6)